

## **GB2293702**

Publication Title:

Contactless electrical power coupling and converter

Abstract:

Abstract of GB 2293702

(A) The coupling comprises a primary air-cored centre-tapped inductance coil 1, inductively coupled to a load, and driven by an oscillatory resonant tank circuit 1a, 1b, 2, two switching transistors 5a, 5b each coupled to a respective side of the tank circuit; and a current source such as +Vin, 0v connected by the switches across alternate sides of the tank circuit at its resonant frequency. A drive circuit is arranged such that in use the current through the primary coil is at least twice the current through either of the switches. The switches 5a, 5b may be bipolars, FETs, IGBTs, or GTO thyristors and are controlled by FETs 12a, 12b alternately switched by an oscillator. An alternative embodiment (Fig 2) has a single primary coil (21) having either side supplied via chokes (23a, 23b). Seventeen drive circuits are located in a housing (35, Fig 3) attached to the contactless coupling which is in the form of a rotary joint (31) having seventeen primary coils Z (37) and seventeen sets of secondary coils (41) having two parts and conductive spacers (42) limiting cross-coupling between adjacent pairs of primary and secondary windings. Uses are in robot arms, radar antennae and spacecraft.

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(58) Field of Search

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## (54) Contactless electrical power coupling and converter

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The switches 5a, 5b may be bipolars, FETs, IGBTs, or GTO thyristors and are controlled by FETs 12a, 12b alternately switched by an oscillator. An alternative embodiment (Fig 2) has a single primary coil (21) having either side supplied via chokes (23a, 23b). Seventeen drive circuits are located in a housing (35, Fig 3) attached to the contactless coupling which is in the form of a rotary joint (31) having seventeen primary coils Z (37) and seventeen sets of secondary coils (41) having two parts and conductive spacers (42) limiting cross-coupling between adjacent pairs of primary and secondary windings. Uses are in robot arms, radar antennae and spacecraft.

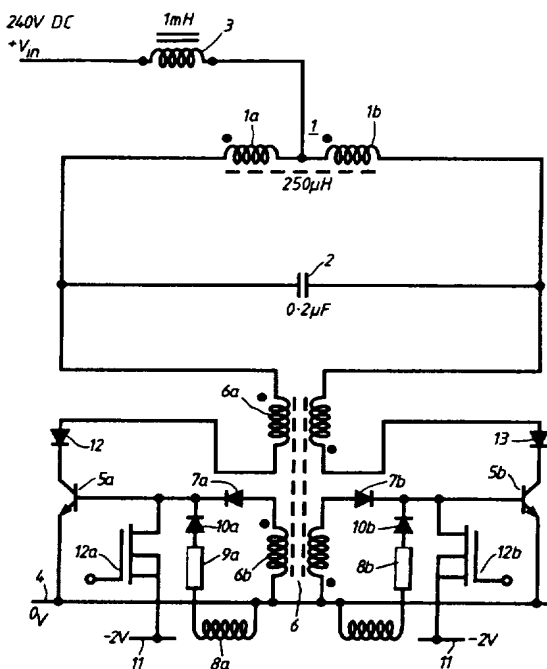


Fig.1

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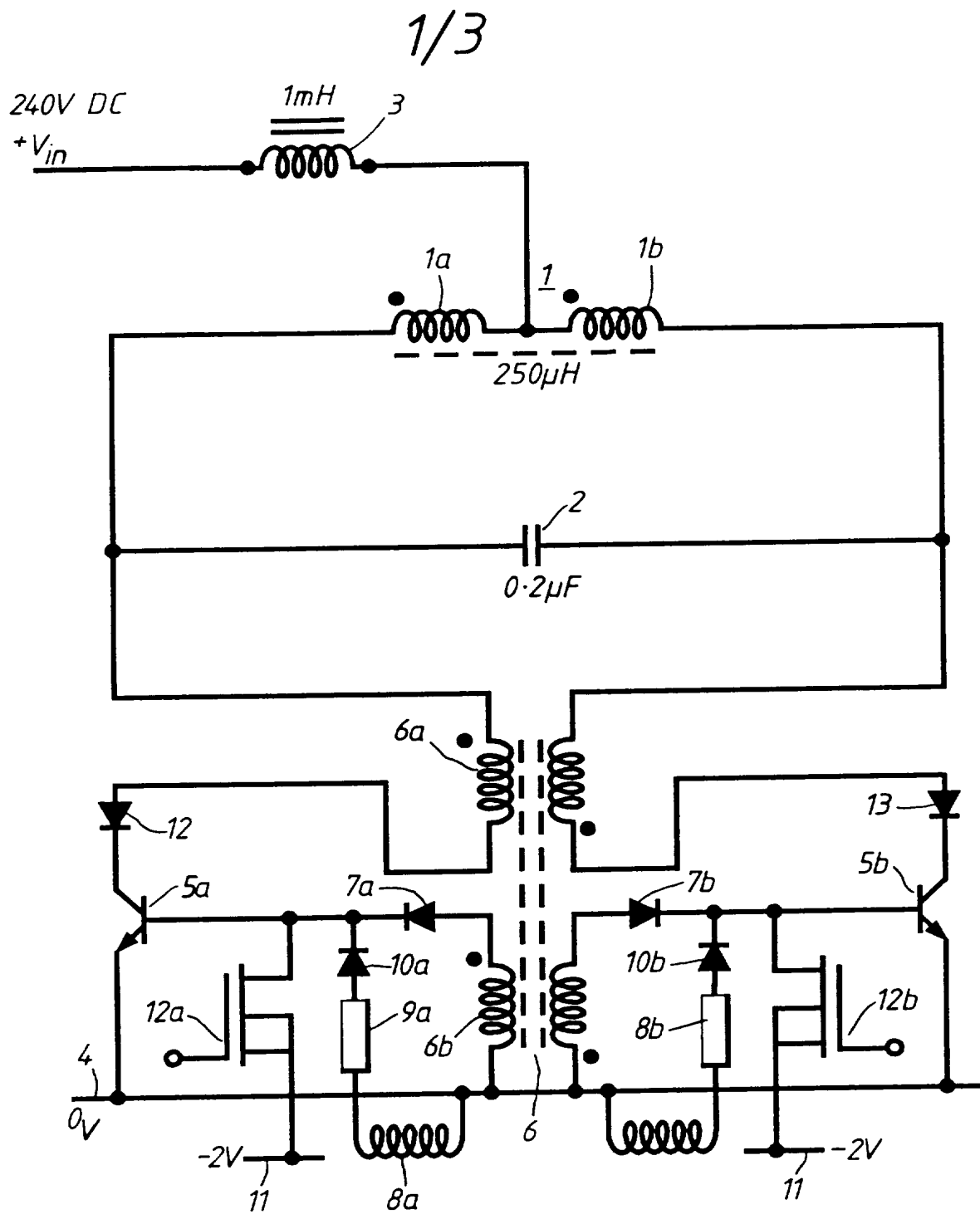


Fig.1

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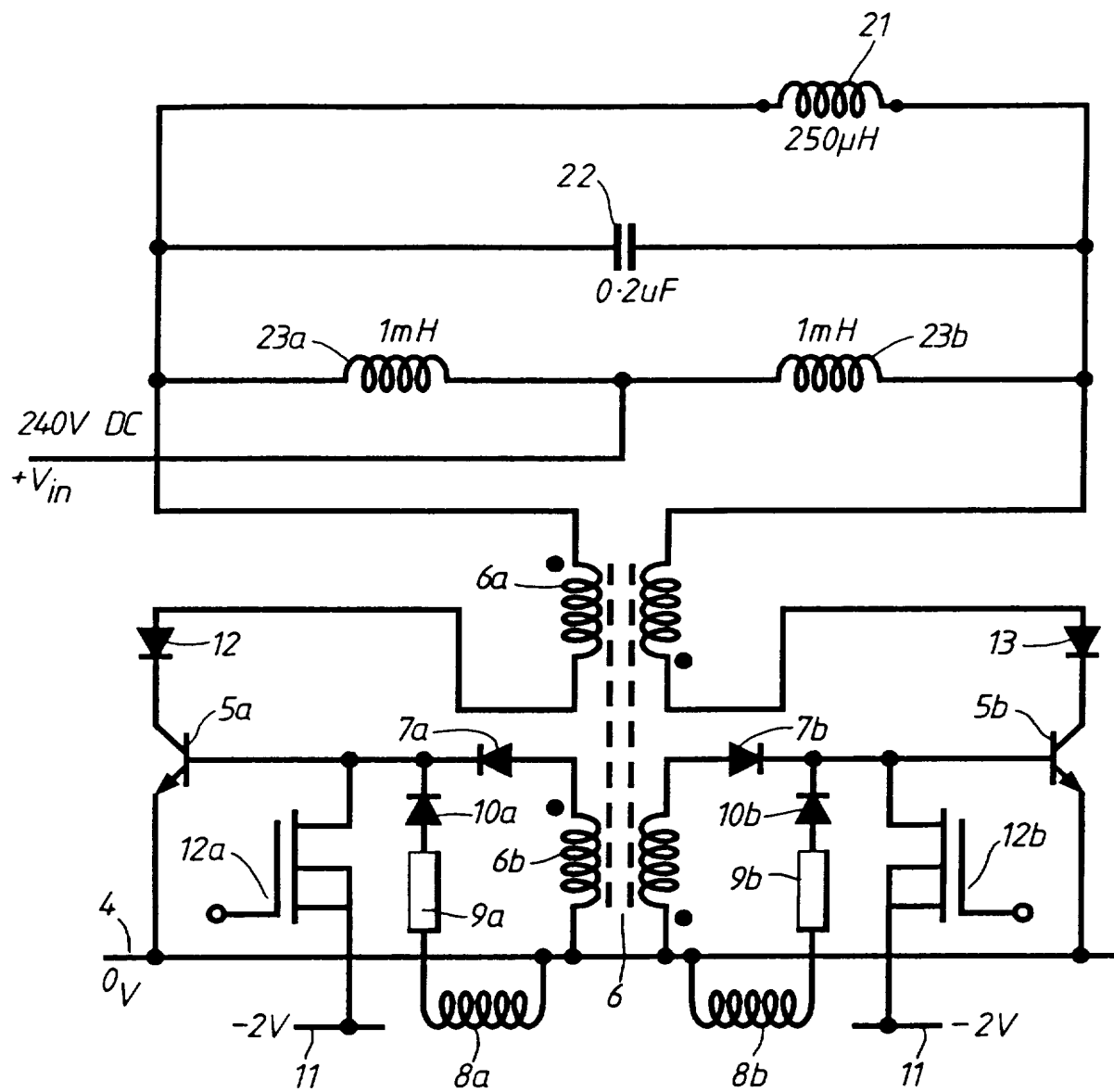


Fig.2



A CONTACTLESS ELECTRICAL POWER COUPLING

The present invention relates to a contactless electrical power coupling and more particularly, but not exclusively to rotating joints incorporating such couplings.

5 There are many examples of mechanical devices embodying rotating mechanical linkages across which is necessary to transmit power or electrical signals, typical examples being robot arms and radar antennas.

10 Power is commonly transmitted across a rotating joint by means of a cable, which cable is routed such that it flexes with the relative movement of the rotating joint. Where a joint continually rotates in one direction it is necessary to occasionally perform a cable "unwrap" manoeuvre. This can be a problem if it is not convenient or practicable to take the device out of operation while the "unwrap" manoeuvre is performed. Also because the cable is continually flexed, it becomes a possible point of failure.

15 In applications where continued operation in one direction occurs slip rings are often employed because they do not limit the number of turns which the joint may undergo. They may also be located off the axis of the rotary joint which may then be used for other purposes. However, slip rings do wear as the joint is rotated, and this wear may result in debris which can interfere with the quality of the contact across the joint, thereby reducing  
20 the reliability of this type of joint. Other problems that can be associated with slip ring arrangements are that the joint often has a high friction torque and a high contact resistance. Because of the aforementioned problems, slip ring joints are not considered to

be particularly reliable and are not suitable for certain applications.

If the signal to be propagated across a rotating joint is a radio frequency signal then this can be transmitted by an on axis waveguide as commonly found in radar applications.

5 However this type of signal propagation is not suitable for normal power transmission applications.

One application which requires a highly reliable maintenance-free means of transmitting power across a rotary joint arises in the field of spacecraft. Here it is often necessary to  
10 transmit power across rotary joints between the spacecraft and limbs attached to the spacecraft. Such limbs may comprise solar arrays or antennas which may have to continually rotate in a certain direction while the spacecraft, for example, orbits a planet. The reliability of the electrical connection between, say, a solar array and the spacecraft may be critical to the life of that spacecraft. Therefore not only must the joint be reliable  
15 but it must also be maintenance-free.

Contactless electrical transmission means are already known, often dictated by safety considerations requiring that electrical isolation is maintained between a power supply and an associated load. Low level signals across such an isolating barrier between the supply  
20 and load can be transferred by capacitive coupling, or opto-electronic means. Such techniques are usually employed for communicating data but can extend to low power energy transfer, typically a few watts. To transmit more than a few watts of power requires a transformer coupling.

Safety standards also often demand a minimum physical separation between exposed primary and secondary side connections, in addition to the electrical isolation between the power source and the load. This suggests that simple axial or coaxial division of the core and windings could provide a contactless power coupling, and radial symmetry suggests that this could be used for a rotary contactless coupling.

Separating the primary and secondary windings leads to an exceptionally high leakage of inductance, but provided a transformer is driven by the appropriate converter circuit, satisfactory power transfer can still be achieved even when the primary and secondary windings are separated provided there is a closed magnetic circuit to confine and concentrate the flux produced by the windings. To have a common core in a rotating joint application it is necessary for the transformer to be mounted on the axis of a rotating joint. In certain applications this is not desirable, for example if the axis is required to carry a waveguide. Furthermore, iron cores are extremely heavy and therefore such a core would not be desirable for a spacecraft application.

Air cored transformers are known where a signal is transmitted from a primary coil to a secondary coil across a gap of one or two millimetres, but because of the spacing between the primary and secondary and the lack of any magnetic core, the flux leakage is so great that such transformers are only suitable for data transmission, or transmission of very low power, one application being the transmission of data from a reader to an induction coil embedded in a contactless "smart card".

According to the present invention there is provided a contactless electrical power coupling



comprising a primary air cored inductance coil, arranged relative to an inductive load such that there is a mutual magnetic inductance between them, and a drive circuit for the primary coil, the drive circuit comprising:

- 5 a resonant tank circuit having inductive and capacitive components arranged such that an oscillating current can be maintained in the tank circuit;
- two semiconductor switching means each coupled to a respective side of the tank circuit;
- and a current source connected by the semiconductor switching means across alternate sides of the tank circuit at the resonant frequency of the tank circuit, the drive circuit being arranged such that in use the current through the primary coil is at least twice the current
- 10 through either of the switching elements.

By employing the present invention it is possible to obtain very high currents through the primary coil whilst having relatively low currents through each of the switching elements. Furthermore, the losses associated with the switching element are fairly small due to

15 voltage across them tending towards a minimum at the moment of switching. Another advantage of the present invention is that the current in the primary can be almost a pure sinusoid thereby reducing the problems associated with harmonics interfering with other equipment.

- 20 The driving circuit may be arranged such that the tank circuit comprises a capacitor connected across the primary coil which is centre tapped, the current source being connected across the centre tap and each semiconductor switching element., and preferably the centre tapped coil is the primary coil. Alternatively the tank circuit comprises two inductors arranged in series across which a capacitor and the primary coil are connected

in parallel, the current source being connected between the two inductors and each of the semiconductor switching elements.

For certain applications it is preferable that the components of the drive circuit are selected such that the peak current through the primary coil is at least ten times greater than current through either of any one of the switching elements, this providing a very high exciting field in the primary for any given current through the switching elements.

The present invention is particularly advantageous where the power coupling has a power rating exceeding one KVA.

Preferably the semiconductor switching means are transistors, either Field Effect Transistors (FETs) driven by a low power oscillator, or alternatively bi-polar transistors, which can operate at higher current values, but IGBTs or gate-turn off thyristors could also be employed.

If bi-polar transistors are employed, then it is advantageous if the base of each transistor is inductively coupled to the respective current flow between the transistor and the respective side of the tank circuit to which it is connected such that said current flow maintains the transistor in an on state. This eliminates the need to provide any further high current source to drive the transistors.

Preferably the base of each transistor is connected to a respective semiconductor switching device by which the base can be driven low, each semiconductor switching device being

driven by an oscillator at the frequency of the resonant tank circuit. This provides a means of driving the transistor low by means of a semiconductor switching means which itself only has to switch the base current of the transistor.

- 5      Advantageously the base of each transistor is also electrically connected to a low supply by an inductive link, the arrangement being such that when one of said semiconductor switching devices is in an on state current is drawn through said inductive link, which current is commutated to the base of the transistor at the transition of the semiconductor switching device to an off state due to the inertia of the inductance, such that the transistor  
10      is rapidly driven into its on state.

- According to a second aspect of the present invention there is provided a rotary joint comprising a power coupling as described above wherein the primary coil is mounted to rotate with one side of the joint, and the secondary coil is mounted to rotate with the other  
15      side of the joint.

- Advantageously the primary and secondary coils are arranged in parallel relationship coaxial with the axis of rotation of the joint. Then when the relative halves of the joint rotate there is no significant change in the mutual inductance between the two coils. Also  
20      the axis of rotation which passes through the centre of the coils is available for other purposes.

The rotary joint can advantageously comprise a plurality of power couplings as described above, and these can preferably be arranged such that the respective primary and secondary

coils are in a stacked relationship. This permits multiple power couplings through the rotary joint which can be used as separate channels. This permits electrical components mounted on one side of the joint to be controlled by means of the power supply, eliminating the need for coding which can be subject to interference. Alternatively the multiple power couplings can be used to provide redundancy in case of failure of one of the couplings.

One embodiment of the present invention will now be described by way of example only with reference to the accompanying drawings, of which:

Figure 1 is a circuit diagram of the driving circuit of the power coupling in accordance with the present invention;

Figure 2 shows an equivalent circuit arrangement to that of Figure 1; and

Figure 3 is a cross section through a rotary joint in accordance with the second aspect of the present invention.

Referring to Figure 1 there is illustrated a drive circuit for a power coupling in accordance with the present invention. This comprises a centre tapped primary coil 1 across which is connected a capacitor 2 which together form a resonant tank circuit. The centre tap of the primary coil 1 is connected to a choke 3 which is connected to a 240V d.c. supply. Each side of the tank circuit 1 is connected to ground line 4 via respective bi-polar transistors 5a and 5b.

The base of transistor 5a is coupled via transformer 6 to the current flowing through the transistor. The base of transistor 5a is also connected to ground, via inductor 8a, resistor

9a and diode 10a, and to a low voltage (-2V) supply line 11a via FET 12a which is connected to a low power oscillator not shown. Transistor 5b is connected to like components in the same manner, with FET 12b being connected to the same oscillator as FET 12a, but in antiphase, the oscillator having a 50:50 duty cycle and a frequency of 25 kHz.

In operation choke 3 acts as a constant current source driving current at a constant rate through the circuit. Assuming that at a given point in time transistor 5a is on and transistor 5b off then the current flows through the first half of the primary coil 1a and FET 5a to ground. Current through the first half of primary coil 1a causes an equal current to flow in the second half of the primary coil 1b, which current returns to earth via capacitor 2.

On switching of transistors 5a and 5b current flows from the choke 3 to ground via transistor 5b in the same manner. The values of the primary coil 1 and capacitor 2 are chosen so that for any given operating conditions the resonant frequency of the tank circuit formed by these components is the same as the switching frequency. The alternate switching of transistors 5a and 5b causes a large oscillating current to be generated in the tank circuit, and therefore through the primary coil 1, which is then coupled to an inductive load, not shown, normally an inductive coil of a rectifying circuit. Typical values of components are given in the figures, for a circuit operating at 25kHz. However the value of the component will be specific to any particular application.

Referring now to the operation of circuitry for driving transistors 5a and 5b, and assuming transistor 5a is initially in an on position and 5b in an off position. Current flow via

primary coil 6a of transformer 6 causes current to flow through coil 6b which maintains transistor 5a in an on state. When the oscillator (not shown) switches on FET 12a on, the base of transistor 5b is driven low and the transistor 5b switches off. With FET 12a in an on state a small current flows from ground 4 via inductance 8a, resistor 9a, diode 10a and FET 12a to the low supply. When FET 12a is next switched off this current flow, which is maintained momentarily by the inductance of inductor 8a, is commutated to the base of transistor 5a quickly driving it to an on state whilst the current flow via transformer coil 6b increases. Transistor 5b is driven in the same way by equivalent circuit components.

Figure 2 illustrates an alternative embodiment where the centre tapped primary coil has been substituted with a single coil 21, the current from chokes 23a and 23b being applied now to either side of the tank circuit, defined by primary coil 21 and capacitor 22. The current is switched and functions in the same manner as that illustrated in Figure 1.

Referring to Figure 3 there is illustrated a longitudinal cross section along the rotational axis 30 of a rotary joint 31. The joint comprises two halves 32 and 33 arranged to rotate relative to each other on bearings 34. The first half 32 of the joint 31 comprises fixing points 33 for attachment to a first member, for example a solar panel of a spacecraft, a housing 35 for seventeen drive circuits as illustrated in Figures 1 or 2, and a cylindrical portion 36 supporting seventeen primary coils 37.

The second half of the joint comprises a flange 38 adapted to be connected to a second member, such that the first and second members are rotatably connected, a housing 39 for rectifying circuitry, cylindrical outer casing 40, and seventeen sets of secondary coils 41

each comprising two parts, one either side of an associated primary coil. Adjacent coils are separated by a conductive spacer 42 to limit cross coupling between adjacent pairs of primary and secondary windings. Thereby seventeen separate channels are provided through the rotary joint whilst still leaving the axis of rotation free.

5

One embodiment of the invention is described above, but it will be realised that many variations in circuitry and physical arrangement of the rotary joint are possible within the scope of the appended claims.

**CLAIMS**

1. A contactless electrical power coupling comprising a primary air cored inductance coil, arranged relative to an inductive load such that there is a mutual magnetic inductance between them, and a drive circuit for the primary coil, the drive circuit comprising:  
a resonant tank circuit having inductive and capacitive components arranged such that an oscillating current can be maintained in the tank circuit;  
two semiconductor switching means each coupled to a respective side of the tank circuit;  
and a current source connected by the semiconductor switching means across alternate sides of the tank circuit at the resonant frequency of the tank circuit, the drive circuit being arranged such that in use the current through the primary coil is at least twice the current through either of the switching elements.
2. A power coupling as claimed in claim 1 wherein the tank circuit comprises a capacitor connected across the primary coil which is centre tapped, the current source being connected across the centre tap and each semiconductor switching element.
3. A power coupling as claimed in claim 2 wherein the centre tapped coil is the primary coil.
4. A power coupling as claimed in claim 1 wherein the tank circuit comprises two inductors arranged in series across which a capacitor and the primary coil are connected in parallel, the current source being connected between the two inductors and each of the semiconductor switching elements.



5. A power coupling as claimed in any preceding claim wherein the components are selected such that the peak current through the primary coil is at least ten times greater than current through either of any one of the switching elements.
6. A power coupling as claimed in any preceding claim with a power rating exceeding one KVA.
7. A power coupling as claimed in any preceding claim wherein the semiconductor switching means are transistors.
8. A power coupling as claimed in claim 7 wherein the transistors are Field Effect Transistors (FETs) and are driven by a low power oscillator.
9. A power coupling as claimed in claim 7 wherein the transistors are bi-polar transistors.
10. A power coupling as claimed in claim 9 wherein the base of each transistor is inductively coupled to the respective current flow between the transistor and the respective side of the tank circuit to which it is connected such that said current flow maintains the transistor in an on state.
11. A power coupling as claimed in claim 10 wherein the base of each transistor is connected to a respective semiconductor switching device by which the base can be driven

low, each semiconductor switching device being driven by an oscillator at the frequency of the resonant tank circuit.

12. A power coupling as claimed in claim 11 wherein the base of each transistor is also electrically connected to a low supply by an inductive link, the arrangement being such that when one of said semiconductor switching devices is in an on state current is drawn through said inductive link, which current is commutated to the base of the transistor at the transition of the semiconductor switching device to an off state due to the inertia of the inductance, such that the transistor is rapidly driven into its on state.

13. A power coupling substantially as hereinbefore described with reference to, and as illustrated in, the accompanying drawings.

14. A rotary joint comprising a power coupling as claimed in any preceding claim, wherein the primary coil is mounted to rotate with one side of the joint, and the secondary coil being mounted to rotate with the other side of the joint.

15. A rotary joint as claimed in claim 14 wherein the primary and secondary coils are arranged in physical parallel relationship coaxial with the axis of rotation of the joint.

16. A rotary joint as claimed in claim 14 or 15 comprising a plurality of couplings as claimed in any of claims 1 to 13.

17. A rotary joint as claimed in claim 16 wherein the respective primary and secondary coils are arranged in a stacked relationship.

18. A rotary joint substantially as hereinbefore described with reference to, and as illustrated in, the accompanying drawings.

**Relevant Technical Fields**

(i) UK Cl (Ed.M) H2F (FDAXS, FDAXT, FDAXX, FDACS, FDUCT, FDACX, FSTC) H1T

(ii) Int Cl (Ed.5) H02M 1/00, 7/42, 7/44, 7/48, 7/53, 7/537, 7/538, 7/5387; H01F 23/00

**Databases** (see below)

(i) UK Patent Office collections of GB, EP, WO and US patent specifications.

(ii) ONLINE DATABASES: WPI

Search Examiner  
 B J EDE

Date of completion of Search  
 13 DECEMBER 1994

Documents considered relevant following a search in respect of Claims :-  
 1-18

**Categories of documents**

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A	GB 1570594	(KOEHLER) see Q1, Q2, 18, 51 Figure 1 and 60, 70 Figures 2 and 3	1
X	GB 1545582	(GENERAL ELECTRIC) see 10, 12 Figure 1	1 at least
X	GB 1545581	(GENERAL ELECTRIC) see 34, 64, 66 Figure 2 and 64, 66, Figures 4 and 5	1 at least
X	WO 94/10003 A1	(DAIMLER BENZ) see Figures 1 and 8	1 at least
X	WO 93/04527 A1	(PIPER) see Q71, Q72, I171, I172, I173, C71, Figure 1 and Figures 8, 9a and 9b	1 at least

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